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Evaluation of the influence of oil volume in hydro-pneumatic suspension system on the characteristics of spring force

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ABSTRACT: *This study shows the influence of oil volume on the spring forceof the hydro-pneumatic suspension system (HPS) of a mining dump truck. Based on the structural model, a nonlinear mathematical model is built to determine the spring and damping force components of the HPS. The influence of oil volumeof HPS on the spring force and damping force is simulated with 1/4 mining dump truck vibration model using Matlab/Simulink software.The analysis results show that the spring force decreases quite strongly during the compression process of the HPS and decreases insignificantly during the rebound process and* the oil volume *value of the HPS increases, the spring force increases quite strongly during the compression process of the HPS and decreases insignificantly during the rebound process.*

KEYWORDS: *Mining dump truck, hydro-pneumatic suspension, spring force, oil volume.*

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I. INTRODUCTION

The oil volume of the HPS is one of the parameters that greatly affects the spring force of the HPS and the ride comfort and safety of vehicle movement.By comparing the pressure, dynamic deflection and acceleration of two types of suspension cylinders through simulation and experiment, the damping characteristics of a two-stage pressure HPS during loading are obtained [1]. The study proposes a new HPS structure based on a high-speed on-off solenoid valve, which can realize two spring force modes and four damping force modes. The mathematical model analysis describes the basic working principles of the HPS with multiple output force modes to establish the damping and stiffness characteristics [2]. The nonlinear spring and damping force characteristics of the HPS have been analyzed by both experimental and numerical methods [3-5]. The research analysis evaluates the effectiveness of the HPS in improving the driving comfort of heavy trucks [6-8]. There are many studies on the force characteristics of HPS, however, the study on the influence of the oil volume of HPS on the spring force is still a scientific issue that needs to be further studied and evaluated. The spring force characteristics of HPS are analyzed based on the vibration model of a 1/4 mining truck with with the vibration excitation source being sinusoidal bumps on the road surface.

II. VEHICLE DYNAMIC MODEL

The structural model of HPS is shown in Fig. 1. The nonlinear dynamic model of the HPS is built with stiffness and damping coefficient as k_h and c_h (Fig. 2) base on the structural model. The pressures of gas chamber (A) main oil chamber (B) and oil chamber (C) are p_A, p_B and p_C. Cylinder inner diameter, rod outer and inner diameter of HPS of front axle are d_a, d_b and d_c. The areas of the orifice and the backflow valve are A_1 and A_2. The vertical displacements of vehicle axle and vehicle body z_a and z_b.

The spring and damping force of HPS

The spring force of the HPS is calculated on the basis of the change in air pressure:

$$F_k = (p_A - p_0)A_b \tag{1}$$

Where, p_0 is initial pressure of air champer of HPS.

The rebound process of gas in the air champer is considered an adiabatic process according to laws of thermodynamics [9] and is determined by:

$$p_0 V_0^n = p_A V_a^n \tag{2}$$

Where, V_0 is initial volume of air champer of HPSs of front axle; V_a is the volume of gas at any position; n is the polytrophic rate.

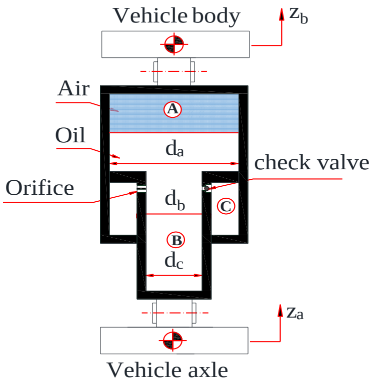

Fig. 1. Structural schematic of HPS

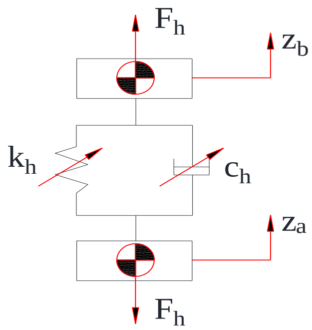

Fig. 2. Nonlinear dynamic model of HPS

From Eq. (2), it can be computed:

$$p_A = p_0 \left(\frac{V_0}{V_a}\right)^n, V_a = V_0 + A_b(z_b - z_a) \tag{3}$$

Combining Eq. (1) and Eq. (3) the spring force of HPS is computed:

$$F_k = p_0 \left(\left(\frac{V_0}{V_0 + A_b(z_b - z_a)}\right)^n - 1\right) A_b \tag{4}$$

The damping force is determined based on the hydraulic loss through the hole:

$$F_c = (p_a - p_c)(A_a - A_b) \tag{5}$$

Where, F_f is friction forces between rod and cylinder of HPSs of front axle.

Based on the flow rate through the hole and the one-way valve, we can determine the pressure relationship between the chambers:

$$p_C = p_B + \left(\frac{\rho (A_a - A_b)^2 (\dot{z}_b - \dot{z}_a)^2 sign(\dot{z}_b - \dot{z}_a)}{2C_d^2 \left(A_1 + \frac{(1 - sign(\dot{z}_b - \dot{z}_a))}{2} A_2\right)^2} \right) \tag{6}$$

Where, ρ is the density of oil, C_d is coefficient of discharge through the hole.

From Eq. (5) and Eq. (6) the damping force of HPSs can be inferred:

$$F_c = -\left(\frac{\rho (A_a - A_b)^3 (\dot{z}_b - \dot{z}_a)^2 sign(\dot{z}_b - \dot{z}_a)}{2C_d^2 \left(A_1 + \frac{(1 + sign(\dot{z}_b - \dot{z}_a))}{2} A_2\right)^2} \right) \tag{7}$$

Based on the determined spring force and damping force, the vertical force of the HPS can be deduced:

$$F_h = F_k + F_c \tag{8}$$

Vibration model

A vibration model of a 1/4 mining truck with the HPS consisting of 2 degrees of freedom is constructed to evaluate the influence of oil volume on the spring force, as shown in Fig. 3.

In Fig. 3, the tire stiffness and damping coefficients are k_t and c_t; the stiffness and damping coefficients of HPS are k_h and c_h; the vertical displacements of front axle, rear axle, vehicle body, are z_a, z_b; the road surface excitations q.

The D'Alambe principle are used to establish a system of differential equations describing the vibrations of the mining dump truck.

Differential equation describing the vibration of the vehicle body:

$$m_b \ddot{z}_b = F_h \quad (9)$$

Vibration equation of the axle:

$$m_a \ddot{z}_a = F_t - F_h \quad (10)$$

Where, F_t is the vertical force of tires:

$$F_t = k_t(z_a - q) + c_t(\dot{z}_a - \dot{q}) \quad (11)$$

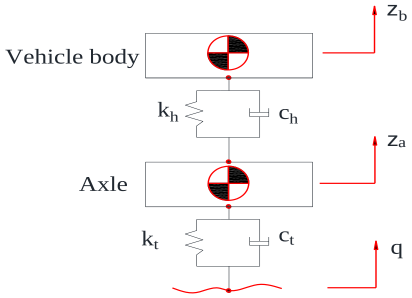

Fig. 3. Dynamic model of ¼ mining dump truck

Sine Road Surface Roughness

In this study, sinusoidal road surface roughness is used as the input excitation source to evaluate the oil volume on the spring force of HPS. When the vehicle moves at a constant speed v, the equation of the excitation function with respect to distance x:

$$q(x) = q_0 \sin\frac{2\pi}{T} t = q_0 \sin\frac{2\pi}{L} vt \quad (12)$$

Where, v, L and $q_0$are the speed of movement, the wavelength of the road surface and q_0 is the maximum height of the sine wave

III. RESULTS AND DISCUSSION

To evaluate the influence of the oilvolume (V_{oil}) parameter, the vibration model of 1/4 mining dump truck was simulated when the vehicle moved on a sinusoidal road surface (q_0 = 3cm and 4cm, L = 4m) at a speed of 30 km/h, the oilvolume of the HPS (V_{oil} = 12dm^3). The parameters of the suspension system and the mining vehicle are referenced in the document [10].

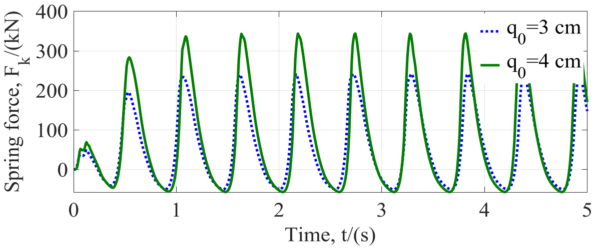

Fig. 4 Spring force of HPS

The simulation results of the spring force of HPS are shown in Fig. 4.The results in Fig. 4 show that the spring force increases rapidly in the compression process of the HPS, the spring force decreases slowly in the rebound process of the HPS. As the road bump height increases, the spring force also increases. The results in Fig. 4 also show that the spring force of the HPS with the case of bumpiness q_0=4 cm increased by 40.1% respectively compared to the case of road bumpiness q_0=3 cm.

To evaluate the influence of the oil volume of the HPS on the spring force, the excitation source oscillated with a sinusoidal road surface bump height (q_0=4 cm, L=4 m), with speed of 30 km/h, and oilvolume values V_{oil}= [10, 12, 14, 16] dm^3 was used for simulation and analysis. The spring force characteristic curve of the HPS according to the displacement and relative velocity between the rod and the cylinder is shown in Fig. 5.

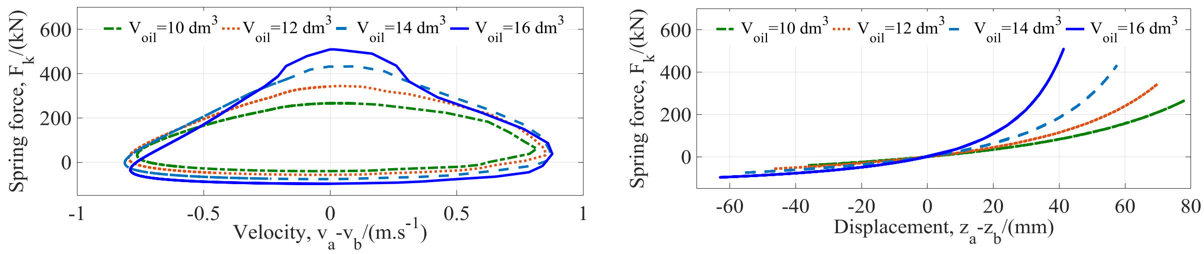

Fig. 5. Spring force characteristics of HPS

The results in Fig. 5 show that the oil volume value of the HPS greatly affects the spring force. The results in Fig. 5 also show that when the oil volume value of the HPS increases, the spring force increases quite strongly during the compression process of the HPS and decreases insignificantly during the rebound process. The maximum amplitude of the relative displacement between the rod and the cylinder also decreases rapidly during the compression of the HPS when the oil volume increases. Compared with the case of oil volumeV_{oil}=10 dm3, the peak amplitude values of the spring force of the cases V_{oil}=12dm^3, V_{oil}=14dm^3 and V_{oil}=16dm^3increases by 29.7%, 62.41% and 91.35% respectively.

IV. CONCLUSIONS

In this study, a nonlinear mathematical model to determine the spring force, damping force and vertical force was built and simulated to evaluate the influence of the oil volume ofHPS with the 1/4 mining truck vibration model. The analysis results showed that the oil volume parameter greatly affected the spring force of the suspension system. The spring force of the HPS in the cases of V_{oil}=12dm^3, V_{oil}=14dm^3 and V_{oil}=16dm^3 increases by 29.7%, 62.41% and 91.35% respectivelycompared to the case of V_{oil}=10 dm3.

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